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RETIREMENT OF MR E. KNIGHTING

With the retirement on 23 April 1974 of Mr E. Knighting, the Meteorological Office lost a leading scientist who had played a large part in the development of both upper-air analysis and numerical weather forecasting since their early days.

When he left the teaching profession in January 1940 to join the Meteorological Office Mr Knighting soon found himself at the Central Forecasting Office, which was settling into its new quarters at Dunstable after being moved from London at the outbreak of war. Later he became a member of the eminent team under the direction of Dr Sverre Petterssen which established the techniques of upper-air analysis and wind forecasting for the wartime Royal Air Force. For the first time upper-air charts were drawn on a regular basis.

Leaving Dunstable in 1949, Mr Knighting undertook research at Headquarters for two years until, on promotion to Principal Scientific Officer, he was posted to Shoeburyness for duty with the Army units there.

Mr Knighting's association with numerical weather prediction began in 1955, when he was sent to Washington to study the methods being developed in the U.S.A. At this time numerical weather prediction had been the subject of active study both in the U.S.A. and in the Meteorological Office for a few years, and the United States Weather Bureau had decided to install its first computer in order to put numerical forecasting into operational practice. Returning to Dunstable after 10 months in Washington, Mr Knighting joined the small group which had been developing dynamical methods of forecasting there. He was promoted to Senior Principal Scientific Officer in 1959 and assumed leadership of the research group engaged in studies related to short-period forecasting. Later, in 1965, Mr Knighting was promoted to Deputy Chief Scientific Officer to fill the post of Deputy Director (Dynamical Research) with wider responsibilities for research in both synoptic and dynamical meteorology. The Meteorological Office College also came under his direction, and received the benefit of his wide knowledge and of his interest in teaching and the training of staff.

A mathematician by early training, Mr Knighting has made many personal contributions to meteorological research. These include studies of the structure of the atmospheric boundary layer in relation to radio propagation as well as

his later researches in the larger-scale aspects of dynamical meteorology. The Meteorological Office will miss Mr Knighting's clear judgement and firm guidance in its research activities.

Mr Knighting's many colleagues and friends in the Meteorological Office and in the many research institutes at home and abroad will, I know, wish him a long and happy future.

J. S. SAWYER

551.507.2

THE METEOROLOGICAL OFFSHORE BUOY OBSERVING EQUIPMENT EXPERIMENT, 1972

By K. J. T. SANDS

Summary. An experiment in which a small offshore buoy equipped with meteorological sensors was used is described. The buoy was on station in Cardigan Bay for three months in the summer of 1972. The results of the experiment are discussed and future plans are outlined.

Introduction. The Meteorological Office and the Directorate of Meteorology and Oceanographic Services (Navy) agreed in 1967 to collaborate in the development of ocean-data buoys. The Meteorological Office was to be responsible for meteorological sensors, data-handling equipment, transmission and recording equipment, and the Royal Navy for oceanographic sensors, buoy platforms, deployment and moorings. This article is partly based on a paper presented at a World Meteorological Organization Technical Conference in Tokyo in 1972.[1]

History. The joint programme began in 1968 when a requirement arose for a small instrumented buoy to be used for air–sea interaction studies in the North Atlantic. The Royal Navy was able to provide a toroidal buoy of diameter 2·5 metres which could be deployed from the deck of a hydrographic research vessel. The toroid is made of a glass-reinforced plastic skin with an expanded polystyrene filling, and the superstructure is constructed from stainless-steel tube.

The initial instrumentation of the buoy was carried out by Messrs Plessey, who provided the recording equipment and interfaced it with sensors specified by the Meteorological Office. The data-handling equipment was an adaptation of an automatic climatological station in which data were stored by a magnetic-tape recorder. The equipment was housed in a watertight container and powered by lead–acid batteries in a separate compartment.

The meteorological sensors were basically those normally used at land stations, but had been modified for the rather specialized application. The experiment was regarded as an excellent opportunity to gain experience in the use of sensors in a marine environment, and measurements were made of pressure, air temperature, air–sea temperature difference, wet-bulb depression and wind speed. These elements were recorded every 15 minutes on ¼-inch magnetic tape.

The sensors were mounted on a horizontal ring about 2 metres above the sea surface. Because toroidal buoys are 'wave-riders' the instruments remain clear of the water even in fairly rough weather. There is a tendency for the buoy to roll, but this can be reduced to some extent by the use of ballast.

The buoy was first tried out during an international air–sea interaction experiment (Operation ATEX) in the North Atlantic tradewind belt in February 1969. It was next used in Operation JASIN (Joint Air Sea Interaction), which took place near ocean weather station Juliett in June 1970. A second buoy of the same type was used to study the performance of pressure transducers in the marine environment. This experiment showed that it was possible to measure pressure to an accuracy of within about $\pm 0{\cdot}5$ mb.

Because these buoys had performed satisfactorily at sea, and because the second buoy offered the necessary data-handling facilities with ample spare channels, it was decided to use this 'test-bed' platform for evaluating marine sensors. If reasonably economic buoys are to be developed for operational service, they are likely to have severe power restrictions, and the system as a whole must provide satisfactory service over long periods without attention. In both respects it is the sensors which give most cause for concern.

The test-bed buoy, now known as the Offshore Buoy Observing Equipment (OBOE IA), marks the first step in a long-term programme of development and evaluation.

The buoy equipment. The original data-handling equipment was retained but several modifications were carried out. In order to provide real-time monitoring of the output of the meteorological sensors, a radio-telemetry link to a shore-station receiver was provided, whilst retaining the recording facility on the buoy as a safeguard against communication difficulties. The recording equipment is capable of handling eight analogue channels, which are switched sequentially to an encoder based on the successive-approximation principle. The signals are converted into 10-bit binary-data words (giving a resolution of 0·1 per cent), recorded serially on to ¼-inch magnetic tape, and at the same time fed to the modulation stage of the radio transmitter. The 10-bit words are transmitted by using a two-tone frequency-shift system, the output power of the transmitter being 2 watts at a frequency of 151·5 MHz. An omnidirectional half-wave aerial, mounted 3·5 metres above the sea surface, is used on the buoy. Lead–acid batteries provide the power supplies, and their capacity is such that the buoy equipment will run for six weeks from a single charge. The internal clock now switches on the data-recording equipment and radio transmitter at half-hourly intervals, a complete transmission cycle taking about 75 seconds. During the 'off' periods, power is supplied only to the clock system. Each sensing transducer provides a voltage in the range 0–5 volts d.c. The block diagram (Figure 1) shows the essential features of the buoy system.

Functions of the channels

Channel 1 provides data on the state of the batteries for four successive transmissions, while the next four transmissions give a reference signal, which makes it possible for the data-handling system as a whole to be calibrated. This sequence is repeated throughout the 24 hours.

Channels 2, 3 and 4. These channels are used for the measurement of temperature. On channel 2, differentially connected electrical resistance thermometers (ERT) are used to measure the air–sea temperature difference in the range ± 10degC by means of a Kelvin bridge and an operational amplifier. Linearity is better than 0·1 per cent. On channel 3, an ERT with Kelvin bridge and interface amplifier is used to measure air temperature in the range $-10°$

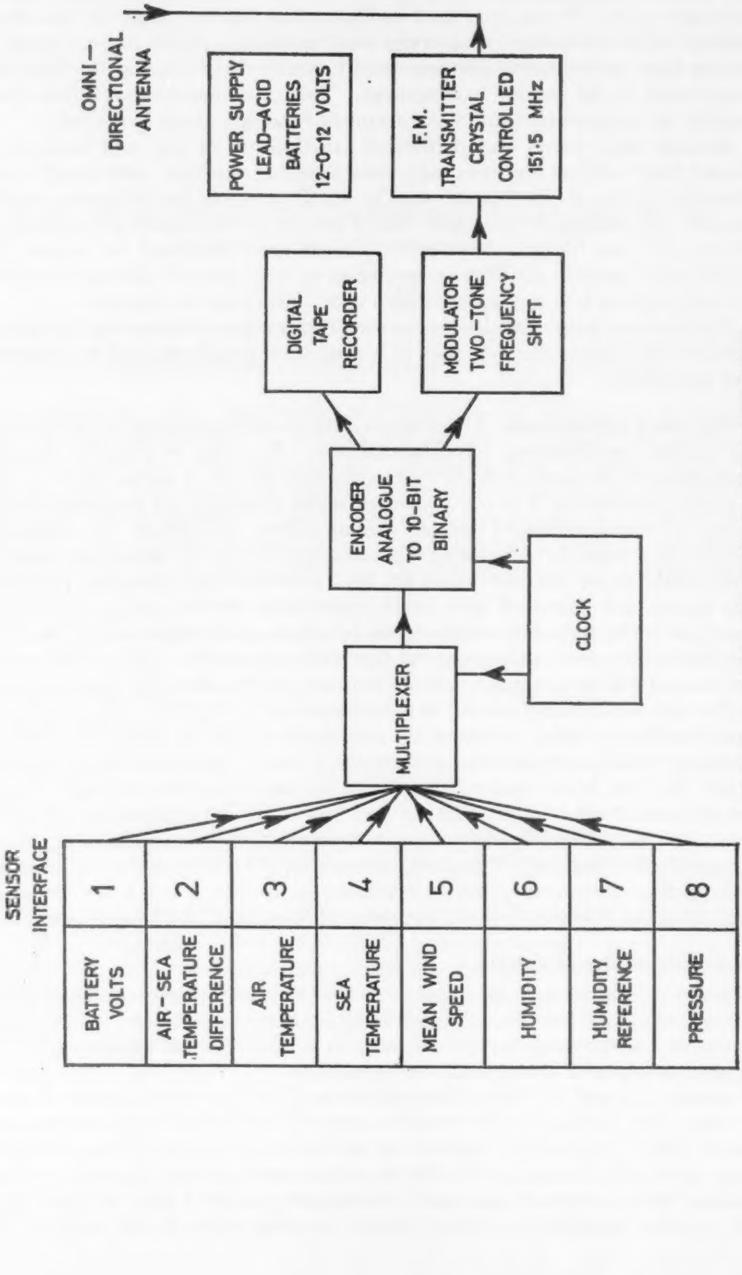

FIGURE 1—BLOCK DIAGRAM OF BUOY EQUIPMENT

to +25°C. On channel 4, a measure of redundancy is provided by the measurement of sea temperature in the range 0° to +20°C. The sea sensors, mounted at a depth of 1 metre, are sheathed in neoprene, and have a time constant of 20 minutes. The air thermometers are exposed in an unventilated marine screen.

Channel 5. A conventional cup anemometer with a.c. generator is used to measure wind speed in the range 3–100 kt via a frequency-to-voltage converter and a 1-minute averaging circuit, linearity being better than 1 per cent. The cup arms are specially strengthened, and the body is modified to prevent the ingress of sea water or spray by the inclusion of a moisture trap. The averaging period is restricted to one minute partly by the power restriction, and partly by the design of the existing timer unit. There would be no difficulty in providing an alternative averaging time if required at a later stage. Wind-tunnel tests have shown that the anemometer calibration does not follow a cosine law when the sensor tilts, rolling movement up to 40° having no significant effect.

Channels 6 and 7. Relative humidity in the range 20–100 per cent is measured with a PCRC-11 element (Phys-Chemical Research Corporation) and a 22-Hz a.c. bridge feeding an a.c.-to-d.c. converter, the output being transmitted on channel 6. On channel 7, the resistance of a second PCRC-11 element, exposed to an atmosphere of known humidity above a saturated salt solution, is measured by the same bridge and associated electronic circuits. Both elements are housed in a second marine screen. Folland[2] finds the PCRC-11 elements to be reasonably stable and apparently washable. Equilibrium is reached within 5 seconds of switching on, and the average power consumption can consequently be reduced to about 10 milliwatts. The sensors are protected by cellulose acetate sheet, 0·025 mm in thickness, from contamination by spray. The elements are individually calibrated in a two-pressure precision humidity generator developed by the Meteorological Office, both before and after use at sea.

Channel 8. A temperature-compensated aneroid barometer with electrical output is used to measure atmospheric pressure in the range 950–1050 mb. The pressure transducer which is a standard commercial product is located in the lower compartment of the data-logger box and vented to the atmosphere through a directional static pressure head. This type of transducer had shown an accuracy of about ±0·25 mb, relative to a working standard, over a period of several months at a land station.

The shore station (Figure 2). Because of the early decision to use the original data-handling equipment on the buoy with the minimum modification, the data format thus determined greatly influenced the design of the shore-station equipment. In the interests of economy, it was decided to use a standard Meteorological Office radio receiver, but, because of the shortcomings in the stability of the receiver at high frequencies, a commercial frequency-converter was introduced to change the incoming signal to a lower and more stable frequency. The signal is received on a six-element YAGI aerial. After FM detection by the receiver, the signal is processed by the Marine Buoy Decoder (see Plate III). The signal decoder has facilities for checking the incoming signal for transmission errors and for holding the complete message in store until the time of the next transmission. The contents of the message store are displayed one word (channel) at a time in the form of decimal numbers in the range 0 to 1023, the word displayed being identified by a channel number 1 to 8. The message can be read, word by word, by means of a stepping switch.

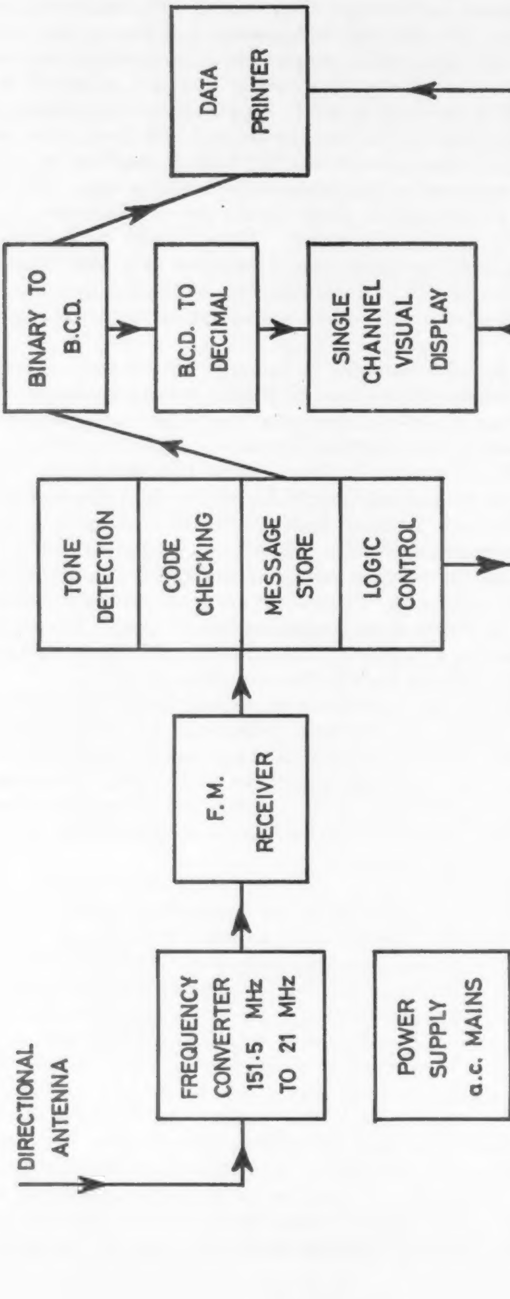

FIGURE 2—BLOCK DIAGRAM OF SHORE-STATION EQUIPMENT
B.C.D. = Binary-coded decimal.

The reading process is non-destructive and can be repeated. After message checking is completed, the data are automatically printed out on a five-column paper roll. The next transmission clears the store of the previous message, the incoming signal restarting the decoding cycle. Once the receiver has been tuned (after a warming-up period) to the buoy frequency, the operation of the shore station is completely automatic. Solid-state electronic components are used throughout the decoder and this gives a very high degree of reliability.

Operation. At the time when the development of the first air–sea interaction buoy began in 1968, a second requirement arose for real-time measurements over the sea near the Royal Aircraft Establishment at Aberporth. For its first sea trials, therefore, it was decided to deploy the buoy in the Irish Sea, some 10 km off the coast at Aberporth. The position chosen is partially sheltered from the prevailing south-westerly winds by a small headland. Calibration and testing of the complete system took place in April 1972 at Beaufort Park, and the equipment was moved by road to Aberporth early in May. The shore station equipment was installed in the Meteorological Office, situated on top of a cliff approximately 130 metres above sea level. Checks for mutual interference by the buoy telemetry equipment and equipment used by the Royal Aircraft Establishment were satisfactory. A further check of the buoy system took place before the buoy was taken to Pembroke Dock in the middle of May. The Royal Naval Dockyard at Pembroke Dock had undertaken the task of placing the buoy on station in Cardigan Bay. After two weeks' delay caused by a combination of bad weather and mechanical mishaps, the buoy was placed on station (see Plate IV) at a point where the mean sea depth is 12 fathoms (approximately 22 metres).

A final check of the sensors and the erection of the transmitting aerial were carried out when the buoy was on station, the first transmission of data taking place at 18 GMT on 1 June. The first few days of operation showed a large percentage of corrupt messages. Measurements made at the shore station revealed that a shift had taken place in the modulation frequency of the radio transmitter. The shore-based decoding equipment was adjusted to allow for the shift and an immediate improvement in data-acquisition occurred. Half-hourly transmissions of data continued throughout June, July and most of August with a recovery rate of more than 90 per cent. All sensors performed well except the pressure transducer, which was later found to have developed an electrical fault. Late in August transmissions from the buoy became intermittent and the buoy was lifted from station on 1 September and returned to Pembroke Dock. The buoy was examined briefly at the dockside and very little damage was noted. The 'electronics' compartment had remained completely sealed and there was no obvious damage to the superstructure or sensors.

Results. The magnetic tape removed from the data-recording equipment at the end of the trial was translated by Messrs Plessey and provided a useful check on the real-time transmitted data. A detailed analysis of these data, together with comparisons with control readings, will be the subject of a later paper. However, initial examination of the data shows that there was good self-consistency in the temperature measurements on channels 2, 3 and 4. Temperature measurements made on land in westerly situations and the occasional sea temperature gave confidence in the data being transmitted. Wind-speed data were compared with readings taken from a floating platform moored 2 km

from the position of OBOE IA and also with selected readings taken at the shore station. After taking into account the difference in exposure appropriate to the three sets of measurements there is fairly close agreement between them. The humidity elements show promise as operational sensors for long-term unattended use on ocean buoys, though there was a drift in calibration of about 5 per cent in relative humidity over the first two months by both sensors.

Conclusions and future developments. This first sea trial with the offshore telemetering buoy has proved its value as a test bed for the exposure and evaluation of marine sensors. It is essential to complete the development and evaluation of a complete suite of reliable marine sensors well in advance of the introduction of networks of operational buoys, automatic light-towers and other suitable platforms. It had been hoped that frequent control readings would be obtained from the trials vessel used by the Royal Aircraft Establishment, but the operation of the vessel in its primary role prevented this from being realized. For any future trials a means must be found of obtaining adequate control readings, for only in this way can the accuracy of the sensors be assessed under all relevant environmental conditions.

After checking and recalibration of sensors and associated electronic circuits, the buoy was redeployed in the Thames Estuary during the period February–April 1973, the shore station being at Shoeburyness. Daily control readings were obtained from the end of Southend Pier (approximately 1·5 km from the buoy), and from the Meteorological Office at Shoeburyness. After some early troubles caused by the ingress of water into the 'electronics' compartment, the buoy again operated satisfactorily, over 95 per cent of the data being recovered. Data from the buoy were passed via Shoeburyness to the London Weather Centre several times each day, and were useful in enabling the Weather Centre to provide up-to-date information to the Port of London Authority in connection with the passage of large vessels up river to the docks. This second trial suggested that OBOE IA could fill an operational role in more or less its present configuration.

In order to make further progress with the general programme of development, a rather larger buoy was needed. The Royal Navy had obtained a 3·5-m diameter steel buoy for use in the joint programme and it is intended to use it as a second test-bed platform for the evaluation of improved power supplies, sensors, data-handling and communication links. This buoy will be known as OBOE II. The number of data channels planned will allow transmission of data on the general state of the equipment, buoy motion, internal temperature of 'electronics', etc., as well as oceanographic measurements. It is hoped that the buoy will operate unattended for 6-month periods. OBOE II should be operating towards the end of 1974.

Acknowledgements. The contribution of Mr D. Painting, who designed and built the shore-station decoder, and the help and advice given by the Hydrographic Department of the Royal Navy are gratefully acknowledged.

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551.593.653

NOCTILUCENT CLOUDS OVER WESTERN EUROPE DURING 1973

By D. H. McINTOSH and MARY HALLISSEY
(Department of Meteorology, University of Edinburgh)

Positive observations of noctilucent clouds (NLC) between 25 May and 8 August 1973, made by the network of observers associated with the Data Centre at Edinburgh, appear in Table I. These dates cover the period of optimum viewing of the clouds between geographic latitudes 50° and 60°N. The period of time during which the clouds were observed appears in the second column, and should not necessarily be taken as the extent of the display; this is stated where possible, but it is obviously difficult, particularly for voluntary observers, to record a display to the point of disappearance. Observations of the characteristics of the observed NLC are entered in the third column. The remaining columns contain observations from selected stations, the latitude and longitude of which are given to the nearest half degree. The maximum elevation and limiting azimuths of the observed cloud field at the stated times appear in the last two columns.

In Table II are listed observations of the clouds on 29–30 June 1971, made at Bunnik in the Netherlands, and in Scotland. In the previously published list[1] 'No NLC' was entered for 29 June 1971. Two 'query' reports had in fact been received for that night. It has, however, always been the practice to withhold from publication any observations considered doubtful, so that although entered in our own records, they were not in the published list. Dr Zwaart's notes and a series of colour photographs now leave no doubt about the presence of the clouds over Denmark, and the queried reports are also published.

TABLE I—DISPLAYS OF NOCTILUCENT CLOUDS OVER WESTERN EUROPE DURING 1973

Date — night of	Times UT	Notes	Station position	Time UT	Max. elev.	Limiting azimuths *degrees*
26–27 May	0210–0240	Bands and wisps drifting towards east and receding slightly. Suspected visible also from southern Scotland 2130–2330 UT.	55°N 4·5°W 52°N 0°	 0222	 20	 010–040
3–4 June	2150	Bands and billows against veil background seen from southern England and suspected visible from north-east Scotland.	57°N 3·5°W 51°N 1°E	0050 2150	 10	 330–020
6–7	0120–0225	Bright display of bands and veil, widespread and beyond observer's zenith at 0200 UT. Display still present at 0225 UT.	52°N 0°	0200	90	
7–8	0050–0220	Faint, diffuse bands and wisps, not so bright as previous night, but 'delicate and beautiful'.	55°N 4·5°W 53°N 0·5°E 52°N 0°	 0050 0150 0145	 5 14 10	 035 340–035 340–020
15–16	2200	Bands seen low in north.	55·5°N 4·5°W			
16–17	2200–2215	Bright veil in northern sky, but no obvious structure.	55·5°N 12·5°E			
17–18	2245–2305	NLC seen from Denmark, brightest in NNE, decreasing brightness with height.	55°N 14·5°E	2245 2305	7 12	020–045
18–19	2220–2325	NLC visible from Denmark. Slowly changing structure from veil and bands, with violent increase of brightness at 2255 UT and billow formation. Greatest brightness 2325 UT when new NLC noted in NE. Western movement of clouds. Observations ended 2325 UT.	55°N 14·5°E	2220 2315 2325	12 15 20	315–045
23–24	2200–2340	Unspectacular low-powered display of NLC. Seen Scotland and Denmark.	55·5°N 4·5°W 55°N 14·5°E	 2200 2210 2255	 10 12 8	 340–045

TABLE I—*continued*

Date — night of	Times UT	Notes	Station position	Time UT	Max. elev.	Limiting azimuths *degrees*
24–25	2120–2310	NLC again visible from Denmark. Weak bands at first visible only through binoculars, increased in brightness, elevation and extent. Observations ended at 2310 UT.	55°N 14·5°E	2140	10	045
				2210	12	340–045
				2310	8	
25–26	2155	Veil and bands of medium brightness seen from southern England, almost to zenith. Cloudy over rest of Britain.	51°N 1°E	2155	52	300–030
27–28 June	2340–0005	Two bands of NLC clearly identified though faint in bright sky. Disappeared into rising dawn.	55·5°N 4·5°W	2340	13	340–005
				2400	13	002–015
28–29	2245–0045	Band of NLC visible from northern England.	55°N 1·5°W	2245	7	340–020
				0045	9	360–030
30 June–1 July	2145–2215	From Denmark low-brightness bands of NLC visible above haze to 15°, with small areas of short-lived NLC at higher elevation.	55·5°N 12·5°E			
2–3 July	2150–0200	NLC, brilliant at times, observed from central and south-west Scotland and northern England. Herring-bone formation, billows and S-shaped bands suggested multiple-layered cloud. Display observed from Denmark with less brilliance.	56·5°N 3°W	2310	21	300–030
				2340	25	300–020
			56°N 4·5°W	2300	18	350–040
				2400	19	320–050
				0010	20	300–045
				0030	14	300–050
				0100	15	340–070
			55·5°N 4·5°W	2239	14	026–040
				2300	20	350–050
				0034	12	
			55°N 4·5°W			
			55°N 1·5°W	2245	12	350–010
				2255	15	330–030
				0045	12	340–020
			55°N 14·5°E	2140	10	300
				2215	12	315–045
				2320	18	315–065
3–4	2145–0050	Weak but widespread NLC seen from Denmark at 2145 UT with band and veil structure, becoming much brighter at 2245 UT. In western Scotland tenuous bands and brighter billows visible until tropospheric cloud obscured forms.	56·5°N 7°W	2350	10	340–045
				0050	10	030
			55°N 14·5°E	2145	25	300–045
4–5	2130–0130	Very bright display of veil, bands and billows. For all observers northern border hidden by cloud banks.	57·5°N 3·5°W	2345	19	330–040
				0015	13	
			56·5°N 3°W	2345	9	010–030
				0015	9	350–040
			56°N 10°E	2130	20	315
			55·5°N 4·5°W			
			54°N 4·5°W	2245	10	315–360
				2345	5	360–020
			53·5°N 3°W	2210	11	330–030
			52°N 8·5°W	2245	9	337–017
8–9	2145–0045	NLC observed from Denmark. Colour photographs show billows at high altitude. New bright veil and bands appeared later at 2325 UT in NE. Formation almost unchanged when observations ended at 0045 UT.	56°N 10°E	2145	40	290–045
				2345	15	045
9–10	2150–2215	Short-duration NLC seen from Denmark, at first with binoculars. Weak bands in NE. Observations hampered by tropospheric cloud.	56°N 10°E			
13–14	2210–0015	Weak display seen from Denmark, maximum brightness 2340 UT. New formations visible low NE as sky became too light to observe.	56°N 10°E	2210	10	
				2340	12	045
15–16	2245–2305	Weak display seen from Copenhagen.	55·5°N 12·5°E			
19–20	0200	NLC seen through gap in tropospheric clouds.	53°N 0·5°E	0200	6	020
23–24	2300–0100	Very bright NLC visible NW from northern Scotland and later, 2350 UT, to NNW from western Scotland. Onset of tropospheric cloud prevented later observations.	58·5°N 3°W	2300	15	315–020
			57·5°N 7·5°W	2350	9	340–360
24–25	2350–0200	NLC seen from western Scotland; no details.	57·5°N 7·5°W			
26–27	0040, 0230	Narrow band of NLC seen from south-western Scotland 0040 UT and again faintly at 0230 UT.	55°N 4·5°W			

TABLE I—*continued*

Date — night of	Times UT	Notes	Station position	Time UT	Max. elev.	Limiting azimuths degrees
28–29	2015–2230 0410, 0422	Reported from Copenhagen as brightest NLC of the season; veil and bands low to north. Bright bands and billows seen very low to north from aircraft over west Atlantic, earlier reporting auroral display.	55·5°N 12·5°E 52·5°N 35°W	 0410 0422	 3 4	 360–050 360–045
6–7 Aug.	0050–0315	Veil with whirls seen from western and central Scotland as tropospheric cloud cleared. Earlier seen as narrow band from western and south-western Scotland.	56·5°N 7°W 56·5°N 3°W 55°N 4·5°W	 0225	 13	 350–060
7–8	2300 0230–0325	Short-lived display. Medium brightness billows seen from north-eastern Scotland, and faintly from central and south-western Scotland.	57°N 2°W 55·5°N 4·5°W 55°N 4·5°W	0230 0315	35 36	350–040 360–080

TABLE II—ADDITIONAL DISPLAYS OF NOCTILUCENT CLOUD OVER WESTERN EUROPE DURING 1971

Date — night of	Times UT	Notes	Station position	Time UT	Max. elev.	Limiting azimuths degrees
29–30 June	2045–2145 2330 0030–0150	From Denmark veil, bands, billows showing clearly against fairly bright sky. From Scotland marked red coloration at lower edge nearest horizon. All observations terminated owing to onset of tropospheric cloud.	56°N 4·5°W 55°N 4·5°W 52°N 5°E	0145 2100	15 10	020–040 315–340

It is felt that wider recognition of the clouds by a very reliable network of observers should now ensure that a high percentage of displays visible in this region is recorded whenever meteorological conditions permit. It is possible, however, that instances of the less obvious presence of noctilucent clouds may pass unnoticed, largely owing to factors hampering observations other than the obvious one of ordinary cloudiness, such as moonlight, lack of eye adaptation or presence of atmospheric dust. Reliable comparison of annual frequency is therefore as yet difficult to make, and it would seem that sheer weight of observational data, both positive and negative, is necessary to enable a reliable estimate of noctilucent-cloud occurrence to be made.

During 1973 the clouds were visible on 26–27 May and 7–8 August, which are near the limits of the optimum viewing period for western Europe. Observations for 11–12, 17–18 August and 8–9 September were received, but are regarded as doubtful, and are not included in the published list. They are, however, mentioned because although the clouds are thought to recede polewards in late summer, the possibility of their appearance in western Europe at other times cannot yet be ruled out.

Numerically, the peak of the observing period, which in 1971 and 1972 occurred in the first half of July, this year (1973) appeared in the latter half of June. Observers in Cambridge and in Denmark stressed the richness of the displays seen this season, but in the British Isles generally this was not the case. Cloudy conditions prevailed in most areas of the country, and from the events listed it is obvious that clear skies over Denmark were instrumental in ensuring that a high percentage of NLC occurrences over western Europe were in fact recorded.

Points of interest in relation to noctilucent clouds, contained in recent papers, are the reports of a 'bright layer' at about 80 km made by Russian cosmonauts,[2] and the suggestion that NLC occurrences be considered in relation to solar activity following the apparent detection, in further rocket experiments at Kiruna in 1970 and 1971, of the presence of heavy metal particles of solar origin in the clouds.[3]

The help of the many observers who have sent their reports, many accompanied by sketches, to the Data Collection Centre at the Balfour Stewart Laboratory, Department of Meteorology, University of Edinburgh, is gratefully acknowledged. Excellent photographs have also been submitted from Prestwick and Denmark of the displays seen on 18–19, 24–25 June, 2–3, 3–4, 8–9 and 13–14 July.

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551.515.3

THE TORNADOES OF 26 JUNE 1973

By K. W. WHYTE

Summary. An analysis of the synoptic situation together with evidence from radar and rainfall records shows that the tornadoes at Cranfield on 26 June 1973 were associated with a severe travelling storm of the wind-shear type. The consideration of some previous occurrences of severe storms and tornadoes demonstrates certain similarities between those occasions and 26 June.

Introduction. On 26 June 1973 at about 13 GMT two tornadoes occurred at the Environmental Sciences Research Unit's laboratory at Cranfield, Bedfordshire. The second of these was strong enough to cause considerable structural damage. Later in the afternoon one or more tornadoes were also responsible for damage to buildings and trees at the villages of Parson Drove and Tydd St Giles near Wisbech in Cambridgeshire, but it seems likely that these were associated with a different storm from that which caused the tornadoes at Cranfield.

The purpose of this paper is not to attempt any comprehensive explanation of the tornadoes of 26 June, as it is recognized that without a dense network of observations a complete understanding of such mesoscale phenomena cannot be hoped for. Nevertheless an analysis of the situation in which the tornadoes occurred shows that this occasion was similar in many respects to several of those on which severe storms and tornadoes have been recorded in the past.

Description of the tornadoes. The electrical anemograph record from Cranfield is shown in Plate I. The first tornado occurred at about 1242 GMT and gave a measured maximum gust of $27\frac{1}{2}$ m/s (53 kt). This caused no damage. The second occurred at 1304 GMT and produced a measured maximum gust of

38 m/s (74 kt). The record ends at this point, as the electrical power was disconnected for safety reasons following the damage to the building. The anemometer was at a distance of about 100 metres from the line taken by the second tornado, so that the speed nearer the centre was probably much greater. The damaged building is shown in Plate II. The maximum gust and the damage which was caused indicate that the second Cranfield tornado was at least of strength F1 on the Fujita scale,[1] and the damage at Parson Drove suggests that the tornado there was probably also of strength F1. It is of interest that the maximum gust at Cranfield was almost the same as the 85-mile/h (74-kt) gust recorded by the Shoeburyness anemometer at the time of the tornado of 20 October 1949.[2] This gust was stated to have been measured on the edge of a 100-yd wide track.

The track taken by the second Cranfield tornado is shown in Figure 1. Tagg[3] has briefly described the events at Cranfield and a more complete description of the damage caused is given in the Building Research Establishment's report.[4]

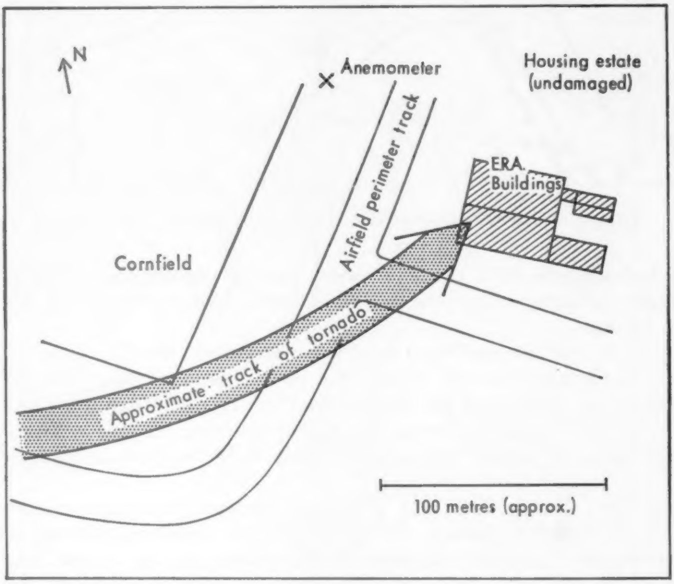


FIGURE 1—PLAN SHOWING THE TRACK OF THE SECOND CRANFIELD TORNADO

Synoptic situation. The surface chart for 12 GMT on 26 June 1973 is shown in Figure 2. A depression of surface pressure 1000 mb was centred over Iceland and its associated cold front, having cleared Scotland and Ireland the previous day, lay almost stationary from Durham to Pembrokeshire through a weak ridge of about 1020 mb which covered Scotland and Northern Ireland. There was a general easterly flow over southern England which was under the influence of a continental depression with its main centre over Spain.

The Icelandic vortex extended throughout the troposphere. Above the 850-mb level the flow over the British Isles, ahead of the upper trough to the

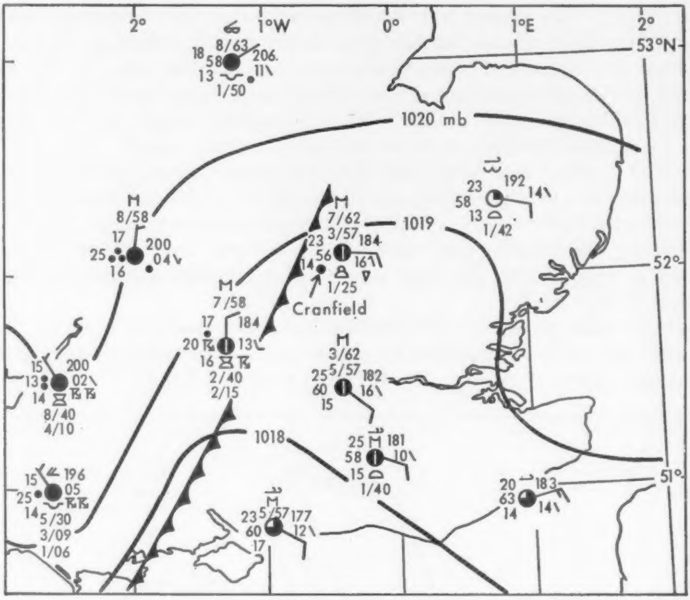


FIGURE 2—SURFACE ANALYSIS FOR 12 GMT ON 26 JUNE 1973

west of Ireland, was from the south-west, veering slightly and strengthening with height. Figure 3 shows the 500-mb contour and 1000–500-mb thickness fields at 12 GMT.

Ahead of the surface cold front there was a large area of rain including some moderate outbreaks over the north and west Midlands and Lincolnshire. Thunderstorms, which were first located over the English Channel in the early hours, broke out in the south-west during the morning, and travelling north-eastwards with the upper flow had reached Wiltshire and Oxfordshire by 10 GMT.

During the morning there was a line of low-level convergence stretching from near the Wash to Dorset. To the south-east light or moderate easterly winds were bringing warm air from the Continent and by 12 GMT temperatures were around 24°C. There were generally small amounts of cumulus below broken cirrostratus and altocumulus. By contrast, to the north-west but south of the Midlands rain-area, skies were overcast, temperatures about 18°C, and the wind was a light north or north-easterly. There was no significant difference across this line in the reported dew-points which were around 14° or 15°C, and the lower temperatures on the north-western side of the line were probably a result of cooling by precipitation combined with a lack of insolation. At 12 GMT a well-marked trough was present in the surface isobars, and the convergence line moved south-eastwards with it during the afternoon as a 'cold front' at a speed of about 5 kt. This anomalous motion against the pressure gradient was probably the result of the isallobaric gradient which was locally sufficiently strong to overcome the effect of the pressure

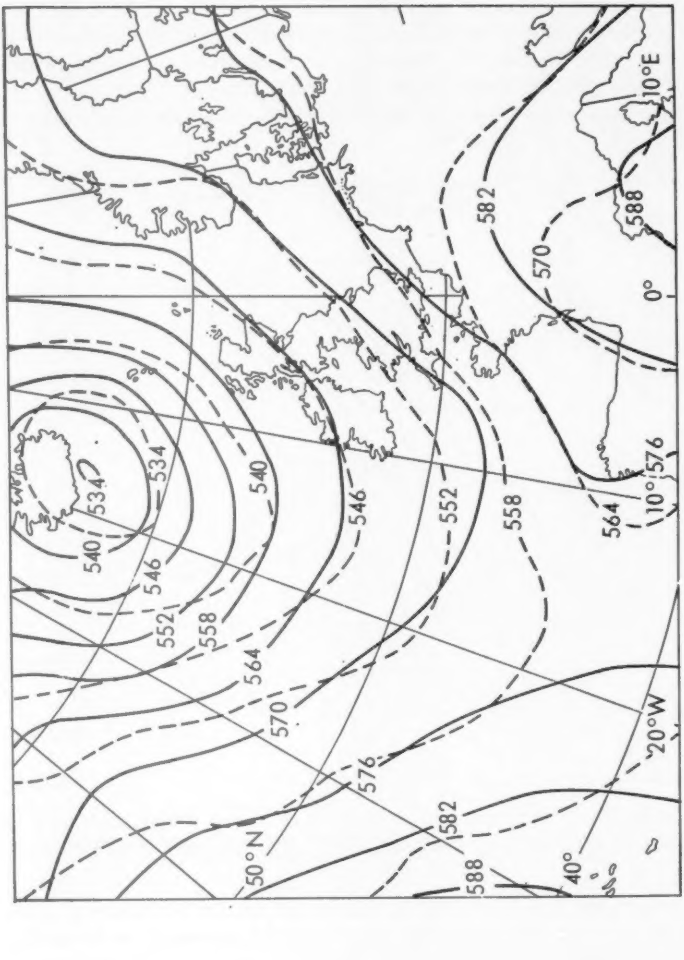


FIGURE 3—500-mb CONTOURS AND 1000–500-mb THICKNESS IN DECAMETRES AT 12 GMT ON 26 JUNE 1973

—— Contours - - - - Thickness

field. The front's progress, which is shown in Figure 4, could be followed by the times of the change in wind direction at the various stations, and it was passing through Cranfield at about the time of the main tornado.

It would seem that one or more of the medium-level storms which were advancing from the south-west developed into a severe storm cell organized on the lines proposed by Browning,[5, 6] and that this cell was maintained by the vertical wind shear between the warm moist north-easterlies at the surface and the upper south-westerlies. In addition the convergence at the surface 'front' in conjunction with the Chiltern ridge may have provided the initial twisting stimulus necessary for the formation of the tornado.

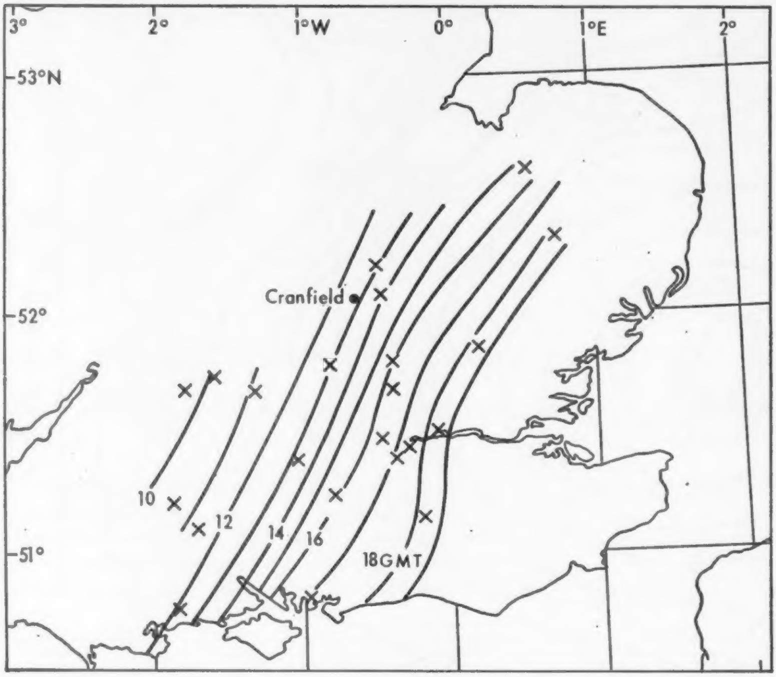
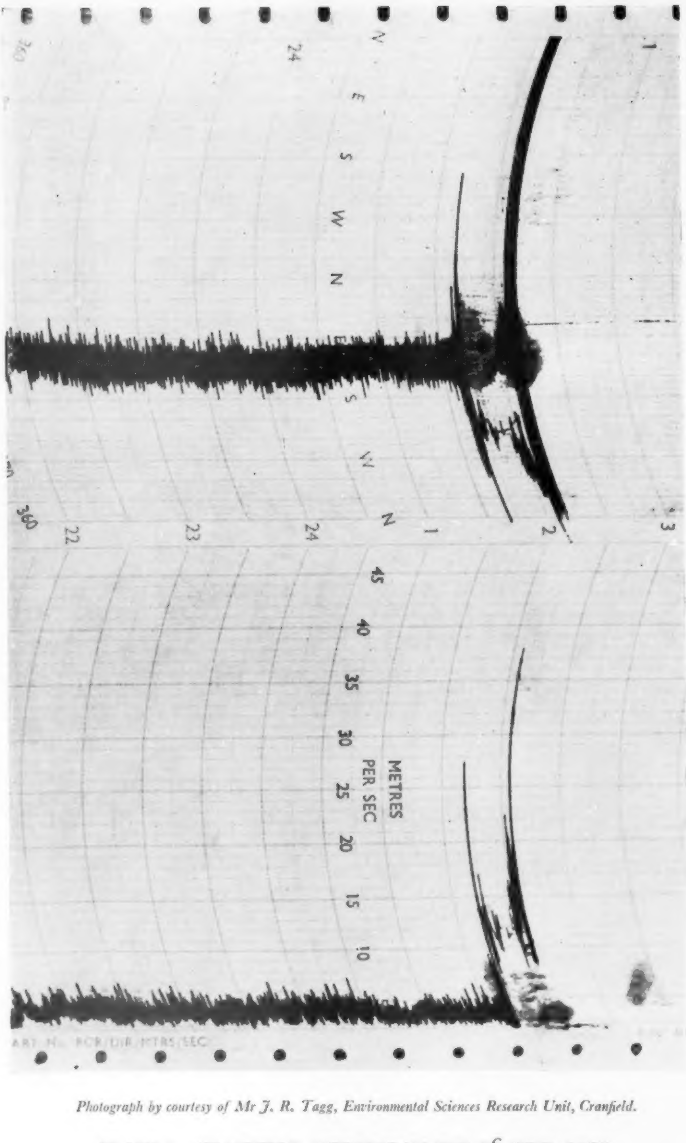


FIGURE 4—SUCCESSIVE HOURLY POSITIONS OF THE COLD FRONT DEPICTED IN FIGURE 2, AS DETERMINED BY ANEMOGRAMS AND WIND REPORTS FROM STATIONS MARKED WITH A CROSS

The Crawley and Hemsby midday ascents are shown in Figure 5. The Crawley ascent is moist, especially below 750 mb, and is unstable to the surface temperature, although only marginally if one takes the lowest 50-mb layer as defining a reasonable parcel. Hemsby's sounding is similar to Crawley's though drier in the lower layers, and the latent instability would be released if the surface temperature were to rise to about 25°C. (During the afternoon there were only a few isolated showers to the south-east of the Wash–Dorset front.) There is certainly no evidence of the stable layer with dry air above, which is considered to be one of the conditions for the formation of severe local storms



Photograph by courtesy of Mr J. R. Tagg, Environmental Sciences Research Unit, Cranfield.

PLATE I—CRANFIELD ANEMOGRAM FOR 26 JUNE 1973

The time scale is in British Summer Time and is incorrect by 12 hours (see page 160).

Photograph by courtesy of Dr K. J. Eaton, Building Research Establishment, Garston.

PLATE II—THE SOUTH-WEST CORNER OF THE DAMAGED ENVIRONMENTAL SCIENCES RESEARCH UNIT BUILDING AFTER THE SECOND CRANFIELD TORNADO

See page 161.

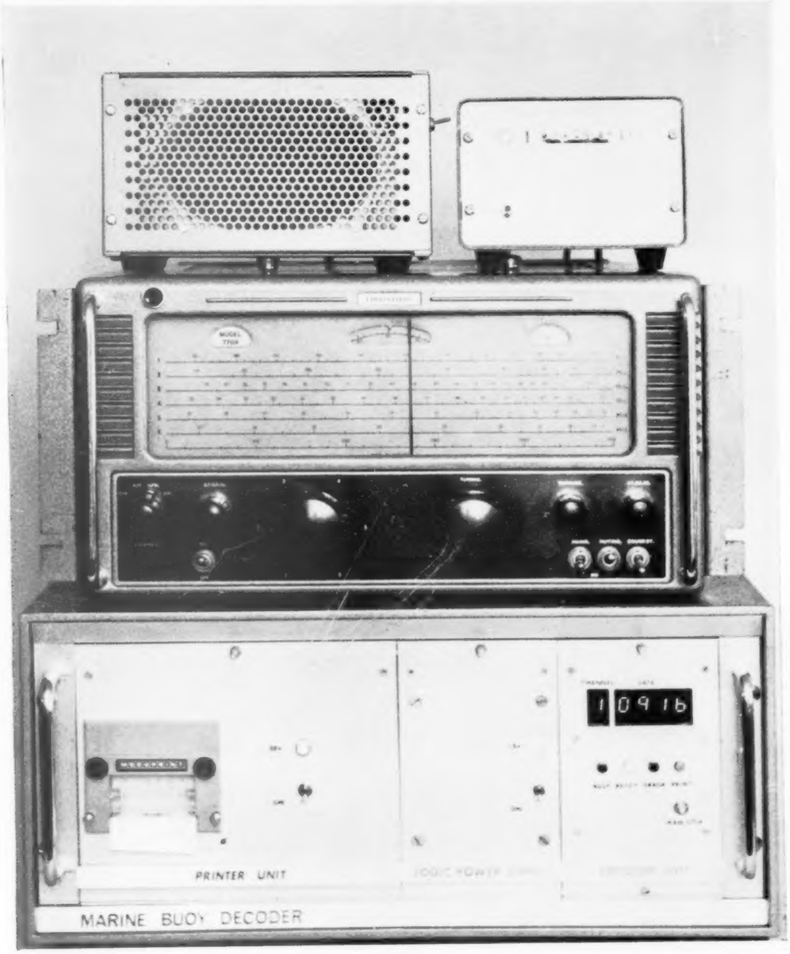


PLATE III—THE SHORE-BASED RECEIVING STATION

See page 153.

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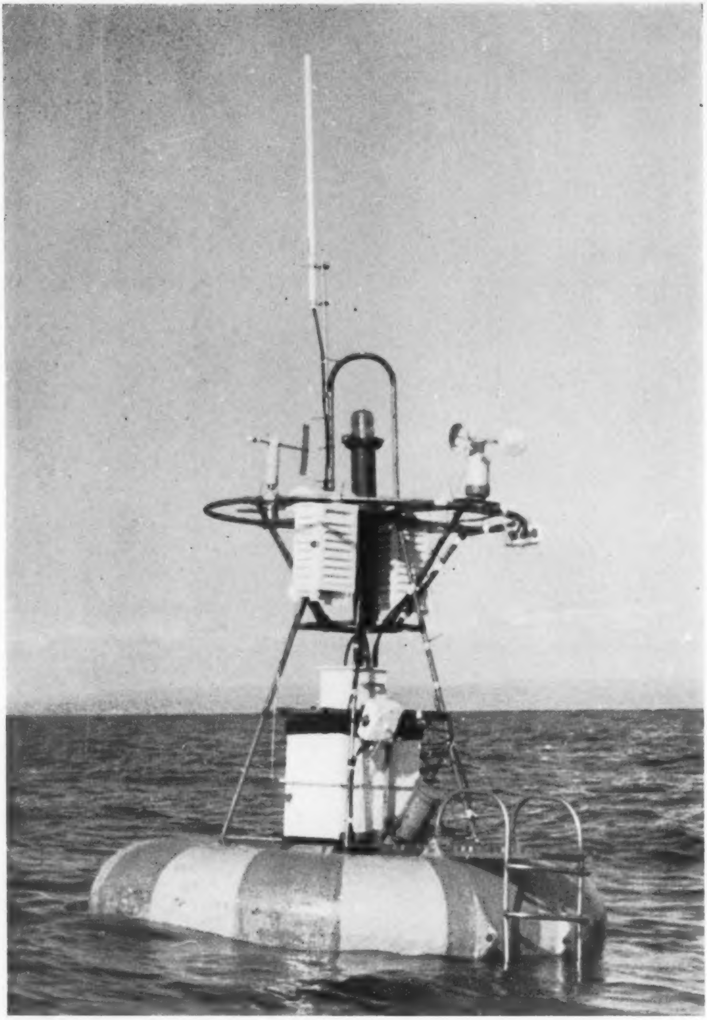

PLATE IV—OBOE 1A ON STATION OFF ABERPORTH

See page 155.

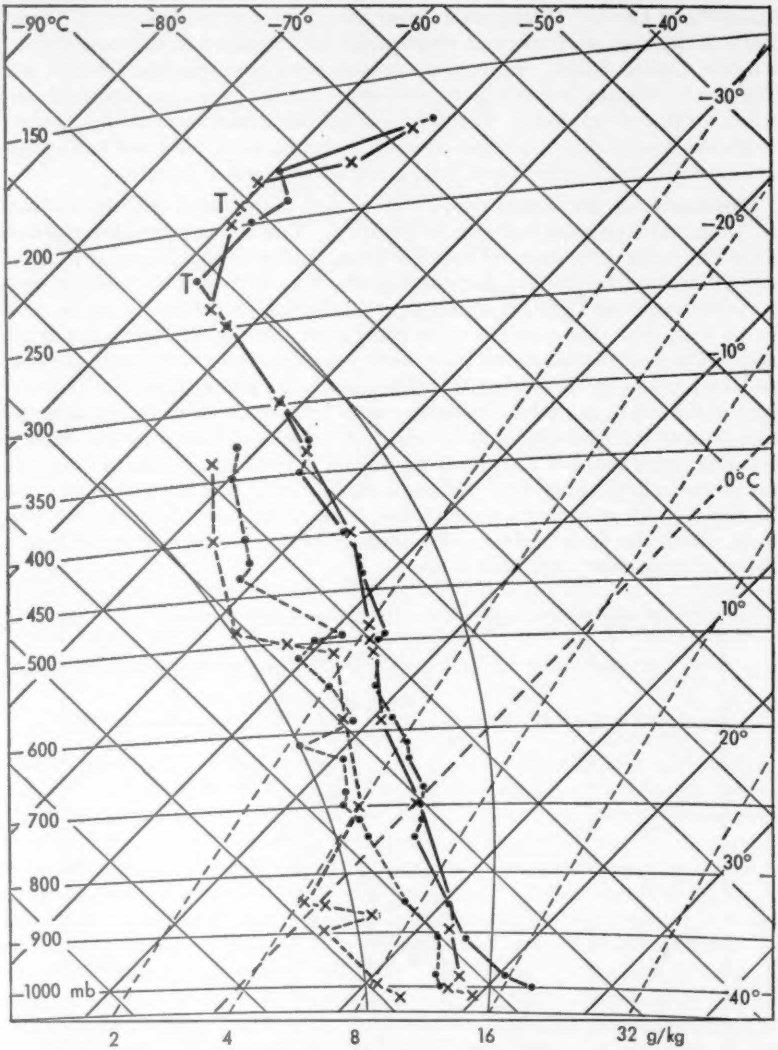

FIGURE 5—CRAWLEY AND HEMSBY TEPHIGRAMS FOR 11 GMT, 26 JUNE 1973

● —— ●	Crawley dry-bulb temperature
● - - - ●	Crawley dew-point temperature
× —— ×	Hemsby dry-bulb temperature
× - - - ×	Hemsby dew-point temperature
T	Tropopause

(See, for example, Newton,[7] Carlson and Ludlam,[8] Browning,[5, 6] and Hardman.[9]) However, in some previous severe storm and tornado situations (e.g. Roach[10] and Lamb[11, 12]) this stable layer has not been in evidence, and it seems that it is not such an important prerequisite for tornadoes in this country as it is in the United States. There is no reason to suppose that the Crawley and Hemsby tephigrams are unrepresentative of conditions in the Cranfield area before the storm's approach. Cranfield was sufficiently far south of the Durham–Pembroke frontal zone and rain-area to be in the same air mass as Crawley and Hemsby, the Wash–Dorset front being only a surface feature.

Movement of the storm cells. The motion of the storm cell which caused the Cranfield tornadoes is shown in Figure 6. This shows successive positions of the PPI radar echo observed from the Royal Radar Establishment at Malvern and determines the speed of the storm as about 20 kt from a direction of 230°. It can be seen from Figure 7, which gives the Crawley and Hemsby hodographs for 12 GMT, that this does not correspond with the tropospheric wind at any level. The storm appears to have been organized on the lines of the 'SR' model proposed by Browning,[5, 6] with substantial inflow from the rear and right of the storm at middle levels, but with little or no deviation in direction from that of the mid-tropospheric wind. The echo observed by the highest-elevation radar beam at 1304 GMT, the time of the second tornado at Cranfield, was of remarkable intensity. Its south-eastern edge was approximately over Cranfield and it extended some 17 miles to the north-west. Unfortunately the storm was too far from Malvern for a reliable estimate to be made of its height. There is no evidence of a hook echo.

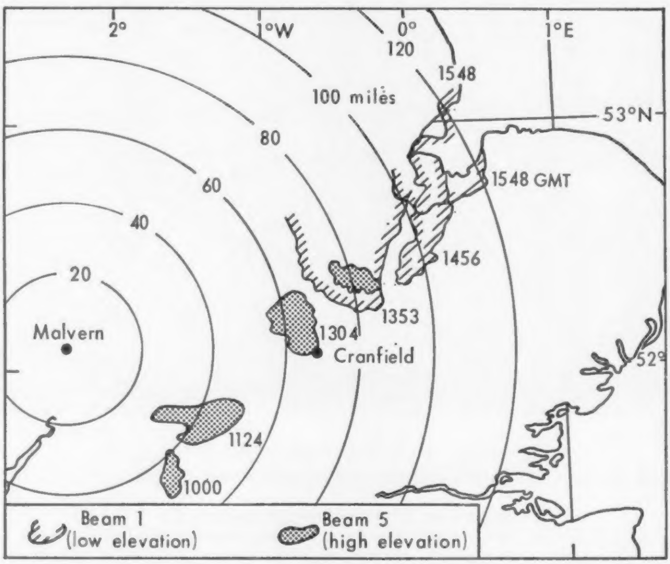

FIGURE 6—SUCCESSIVE POSITIONS OF THE RADAR ECHO FROM THE STORM WHICH PRODUCED THE CRANFIELD TORNADOES

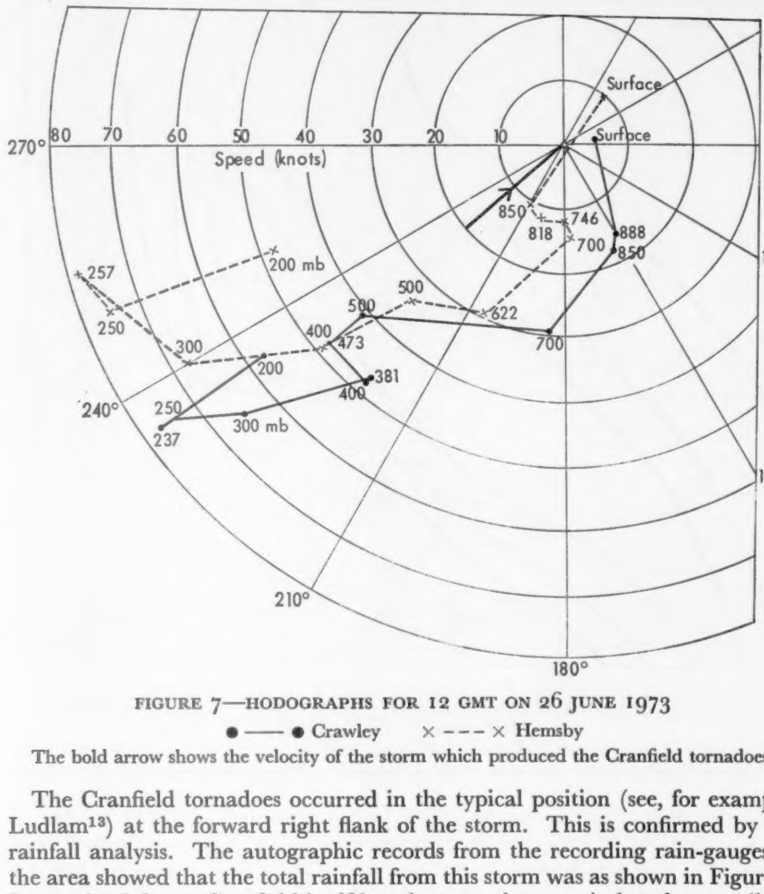

FIGURE 7—HODOGRAPHS FOR 12 GMT ON 26 JUNE 1973

● —— ● Crawley × - - - × Hemsby

The bold arrow shows the velocity of the storm which produced the Cranfield tornadoes.

The Cranfield tornadoes occurred in the typical position (see, for example, Ludlam[13]) at the forward right flank of the storm. This is confirmed by the rainfall analysis. The autographic records from the recording rain-gauges in the area showed that the total rainfall from this storm was as shown in Figure 8. It remained dry at Cranfield itself but there was heavy rain less than a mile to the north-west. Farther north there were several reports of hail and the Royal Aircraft Establishment (RAE) at Bedford (13 miles north-north-east of Cranfield) reported heavy hail with large hailstones ($1\frac{1}{2}$–2 cm in diameter) for 10 minutes between 1315 and 1330 GMT. The storm's gust front gave rise to maximum gusts of 42 kt at RAE Bedford at 1325 GMT and 51 kt at Wyton (28 miles north-east of Cranfield) at 14 GMT, and by 1548 GMT the storm cell was situated over the area around the Wash and was still active enough to give 11 mm of rain in just over an hour at Wisbech.

At the time when the storm which produced the Cranfield tornadoes was moving away over the Wash, a continuous line of precipitation including several distinct cells was oriented north–south from near Lincoln to south of Bedford. The Malvern radar had now ceased operation but the line of storms could be followed (though with poorer definition) by referring to film from the Eastern Air Traffic Control Radar at RAF Watton in Norfolk. This showed

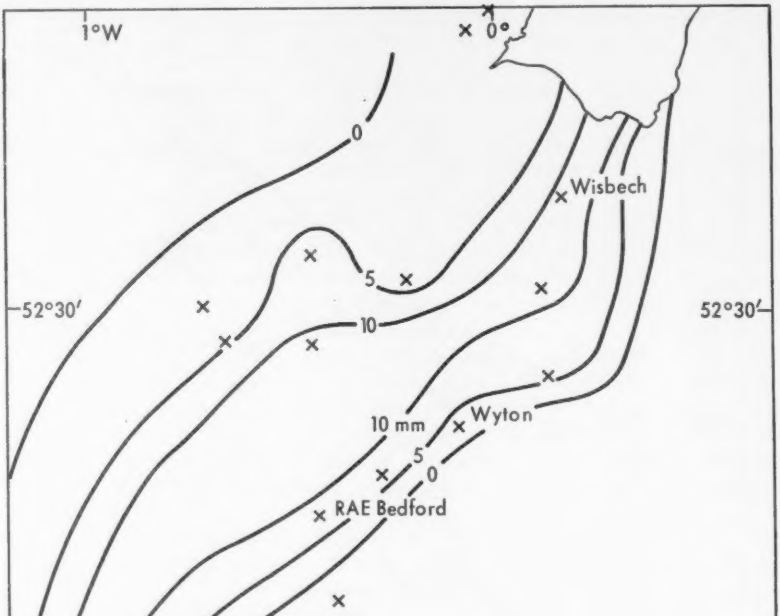

FIGURE 8—RAINFALL FROM THE STORM WHICH PRODUCED THE CRANFIELD TORNADOES ON 26 JUNE 1973

The positions of autographic rain-gauges are marked by crosses. The records from four autographic rain-gauges outside the area of the map were used to assist in drawing the isohyets.

that one cell in this line was in a position to cause the tornadoes at Parson Drove and Tydd St Giles if these had occurred on its right flank shortly after 17 GMT, the time at which they are reported to have caused damage. So this second outbreak seems to have been caused by another severe storm of the wind-shear type, but there is no evidence this time of any convergence line or topographic stimulus for the tornado formation.

The total rainfall for the 24-hour period from 09 GMT on 26 June is shown in Figure 9. This is a combination of the rainfall from several storms whch occurred during the afternoon and evening and shows how they followed much the same south-west to north-east track.

Comparisons with similar situations. The causes of tornadoes are still imperfectly understood. A favourable vorticity field and strong convection are obviously required, and Foster[14] has proposed a predictive index for the United States which is a combination of 'vorticity acceleration' and air-mass instability. A further requirement for tornado generation seems to be the persistence of vigorous convection over a sufficiently long period, so it is only in the 'severe mature' stage of Browning's model[5, 6] that tornadoes can be expected to occur. The importance of 'steady-state' convection is evidenced by the formation of

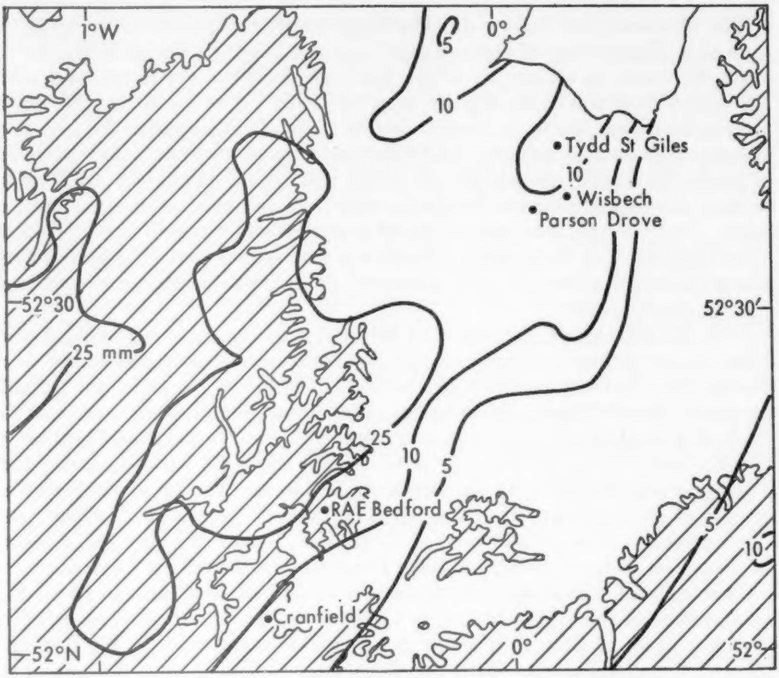

FIGURE 9—TOTAL RAINFALL FOR 24 HOURS FROM 09 GMT ON 26 JUNE 1973
Isohyets are given for 5, 10 and 25 mm. Shading represents land over 200 ft in altitude.

vortices under the cumulus which developed as a result of the *Torrey Canyon* fire[15] and in comparable circumstances elsewhere, for example, the Surtsey volcanic eruption.[16]

Tornadoes are by no means as infrequent in Britain as is generally supposed. Lacy[17] listed 78 observations on 36 days in four years, and others must presumably have gone unrecorded. However, the overwhelming majority of these were not connected with severe storms and many not even with thunderstorms. Most of these tornadoes were of course comparatively minor phenomena, being not especially violent, causing no great damage and rapidly dissipating. The really destructive tornadoes are generally associated with cumulonimbus clouds, and in particular with severe local storms. These occurrences are comparatively rare in this country, but several have been well documented in the past and have shown certain similarities to the subject of the present investigation.

Lamb[11, 12] has described in great detail the events of 21 May 1950, when three tornadoes occurred in much the same area as those of 26 June 1973, and two of these in fact passed within five miles of Cranfield. Though the mesoscale frontal structure and pressure distribution as analysed by Lamb are both very complicated, the situation in eastern England is really quite similar with a surface trough oriented from south-west to north-east dividing easterlies from north-easterlies and upper flow which was clearly south-westerly.

The situation just before the Horsham storm on 5 September 1958[18, 19] showed a distinct line of convergence from the Wash to Portsmouth. In the south the winds on either side of this line were from the north and east, while the upper flow was from slightly west of south. The storm moved north-eastwards, giving rise to a tornado on its right flank opposite the region of heaviest hail near Horsham. The London storm of 27 June 1947[20] occurred in somewhat similar circumstances. There was a weak north-west wind at the surface, spreading from the Midlands with frontogenetic action near the east coast. The 700-mb flow was southerly and winds at Larkhill were southerly up to 450 mb. The storm gave a maximum gust at Croydon of 64 kt and there was a report of a tornado at Colchester, though this appears to have been comparatively weak.

With the Wiltshire hailstorm of 13 July 1967[9] there was strong vertical wind shear but no definite convergence line at the surface. The nature of the wind damage gave indirect evidence of a tornado although no tornado was actually observed. Roach[10] states that the Barnacle tornado of 21 April 1968 was the result of 'a wind-shear' storm organized on the lines of Browning and Ludlam;[21] here the storm occurred some 35 miles behind the main surface convergence zone, but was triggered by an advancing cold front. The south Yorkshire tornado of 26 September 1971 described by Wright[22] was also associated with a thunderstorm in an area of vertical wind shear, though it is doubtful whether this storm could be classed as a severe local storm in Browning's sense.

Conclusions. Evidently the Cranfield tornadoes were associated with a severe storm of the wind-shear type. The Tydd St Giles and Parson Drove tornadoes resulted from a different storm, which was similar to the first and followed a parallel track. Both occasions were typical in that the tornadoes occurred on the right flank (i.e. to the south-east) of the parent storms.

Comparable synoptic situations have given rise to severe storms and tornadoes in the past, though no investigation has been made of occasions which were apparently favourable for the occurrence of severe travelling storms but when they failed to develop, or of severe storms, such as the Wokingham storm of 9 July 1959,[21] which had no associated tornado.

The advice of Miller and Starrett,[23] that tornadoes should be predicted in exceptionally severe thunderstorm situations, may be debatable, but there is no doubt that the events of 26 June 1973 emphasize again the risk of tornadoes occurring in these circumstances.

Acknowledgements. The Environmental Sciences Research Unit (College of Aeronautics, Cranfield) and the Building Research Establishment, Garston, Herts., gave much useful assistance, and various authorities co-operated in providing autographic wind and rainfall records.

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RAPID PRESSURE RISE FOLLOWED BY AN OSCILLATION OF PRESSURE DURING THE PASSAGE OF A TROUGH AT LIVERPOOL AIRPORT ON 5 DECEMBER 1972

By J. A. YOUNG
(Meteorological Office, Liverpool Airport)

Summary. On 5 December 1972 a pressure rise of 3 mb to 3½ mb in around 30 minutes occurred at Valley and Blackpool in association with a marked trough moving eastwards. As the trough crossed the Liverpool and Manchester areas the pressure rise became even more rapid and was followed by an oscillation of pressure. The synoptic situation on 5 December 1972 suggested that an upper-level disturbance was relevant to this occurrence.

Introduction. A marked trough passed through Liverpool at about 1925 GMT on 5 December 1972 and was followed by a rapid pressure rise (3 mb in 25 minutes). After reaching the peak of the rise the pressure fell again even more rapidly (0·8 mb in 2 minutes) before rising again more slowly and eventually levelling off (see Figure 1).

This appeared to be an unusually large rate of change of pressure and it was decided to compare it with changes due to this trough recorded at other stations.

Synoptic situation. The surface analysis for 12 GMT on 5 December 1972 showed a vigorous depression just west of the Hebrides and its associated cold front lying north-north-east–south-south-west, just to the west of Liverpool. The front cleared Liverpool at about 13 GMT and during the afternoon it continued to move quickly eastwards; by 18 GMT it was lying from the Wash

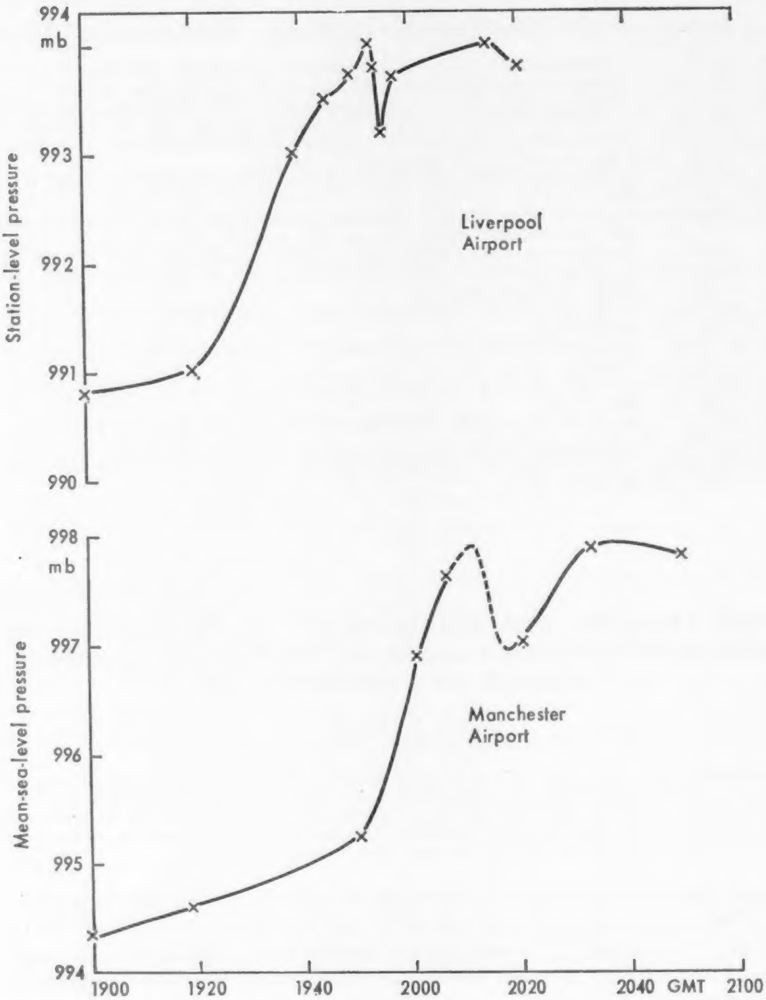

FIGURE 1—GRAPHS OF PRESSURE CHANGES AGAINST TIME FOR PRESSURE CHANGE ON TROUGH

On the graph for Manchester Airport the pecked part of the trace is the suggested shape based on the barogram (no readings were taken between 997·6 mb at 2007 GMT and 997·0 mb at 2020 GMT).

to the Isles of Scilly (see Figure 2). The depression moved north-eastwards at about 40 kt* during the afternoon, and an associated trough moved eastwards at about 30 kt across Scotland, Ireland and the Irish Sea, and was lying from Anglesey to Morecambe Bay at 18 GMT (see Figure 2). It was this trough which was associated with the marked pressure change.

An upper trough moved eastwards across the British Isles ahead of the surface frontal system, followed closely by a westerly upper jet stream (at around 300 mb) which gradually increased in strength as it extended across the British Isles.

Comparison of pressure changes at Liverpool with those at other stations. Details of rainfall, temperature, pressure and surface wind associated with the passage of the trough at various stations are shown in Figure 3 and in Table I. Similar details for Ronaldsway, Isle of Man, showed no evidence of a trough.

TABLE I—DETAILS OF SURFACE WIND ASSOCIATED WITH PASSAGE OF TROUGH

Station	Details of surface wind	
	degrees	*knots*
Valley	230	23, gusts 35, with abrupt veer at 1747 GMT
	to 290	20, gusts 37
Blackpool Airport	230	20, gusts 29, with abrupt veer at 1825 GMT
	to 270	17, gusts 28. Isolated gust 43 kt at 1825 GMT
Liverpool Airport	230	20, gusts 32, with abrupt veer at 1923 GMT
	to 300	23, gusts 36
Manchester Weather Centre	230	20, gusts 38, with abrupt veer at 1945 GMT
	to 290	19, gusts 36
Manchester Airport	250	25, gusts 35, with abrupt veer at 1948 GMT
	to 310	20, gusts 34. Isolated gust 42 kt at 1920 GMT

These details refer to the 30 minutes on either side of the time of passage of the trough with directions in degrees true. The values for the gusts are the highest speeds reached at least five times in the 30 minutes.

The pressure rise. A pressure rise of 3–3½ mb occurred at all the stations shown in Figure 2, but at Valley and Blackpool it was not as rapid as at the other three stations.

A general slow and gradual rise of pressure occurred over Ireland behind the trough. These rises became more pronounced after 16 GMT as the depression moved north-eastwards away from northern Scotland with a maximum rise at around the time when the trough crossed the Liverpool area.

Much larger rises of pressure occurred over Scotland (in the range 6 mb to 9 mb in 3 hours) associated with the movement of the depression, but they were not so steep as those which occurred at Liverpool and Manchester on the trough.

The latter particularly rapid rise may be explained by a small rise due to the passage of the trough coinciding with a more general rise over the west of the British Isles due to the movement of the depression.

The oscillation of pressure. This was the most striking feature of the pressure change at Liverpool Airport (and the initial spur to the preparation of this report). The fall of pressure after the peak of the original rise was even more rapid than the rise itself, followed by a more gradual rise up to the value of the original peak. The barograms for Manchester Weather Centre and

* 1 kt ≈ 0·5 m/s.

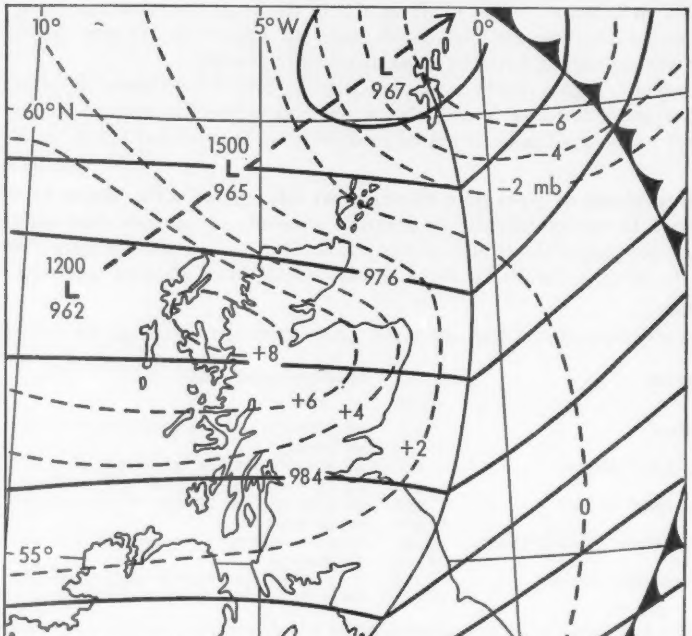

FIGURE 2—SURFACE ANALYSIS FOR 18 GMT ON 5 DECEMBER 1972

The dashed lines are isallobars (lines of equal pressure tendency) in whole millibars per 3 hours at 2-mb intervals. Positions of centres at 12 and 15 GMT are also indicated.

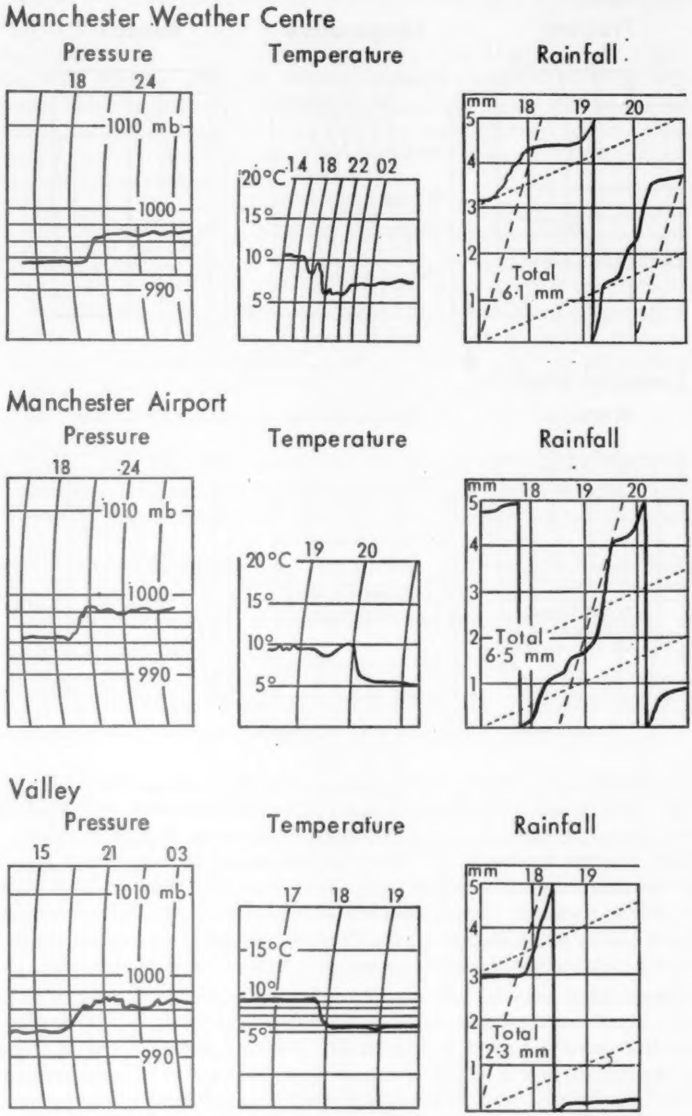

FIGURE 3—DIAGRAMMATIC REPRESENTATIONS OF PRESSURE, TEMPERATURE AND RAINFALL TRACES ASSOCIATED WITH PASSAGE OF TROUGH

All chart times are GMT. On the rainfall charts the pecked lines indicate an intensity of 4 mm/h and the dotted lines one of 0·5 mm/h.

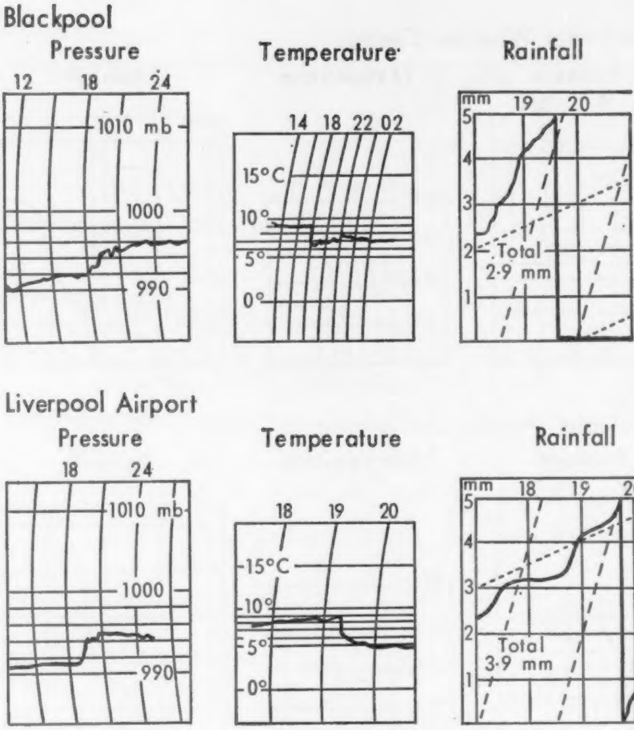

FIGURE 3—*continued*

Preston also showed a similar oscillation, as did the readings from Manchester Airport. The graph of pressure against time at Liverpool and Manchester Airports, based on their observed readings, is shown in Figure 1. Valley and Blackpool Airport showed no evidence of such an oscillation.

To summarize the pressure changes at Liverpool with those at other stations: all the stations shown in Figure 2 showed a rapid rise of pressure; no oscillation showed at Valley or at Blackpool; the Preston barogram showed an oscillation, and a quite marked oscillation occurred at Liverpool and Manchester.

Factors which may be relevant to the occurrence. There is no evidence that this occurrence was associated either with an inversion or with thundery activity, but there was an upper jet stream (around 300 mb) close to the area.

The oscillation in the rising pressure appeared at the Manchester Airport office almost exactly 20 minutes after the same phenomenon appeared at Liverpool Airport. On the assumption that it occurred along a line orientated roughly north to south (it also showed up on the Preston barogram) this gives a speed of movement of 63 kt between Liverpool and Manchester Airports. This fits in with the winds shown on the 12 GMT and 18 GMT soundings from Aughton (60–70 kt from 850 mb to 700 mb, with a steady increase above 700 mb up to the jet-stream maximum of 120 kt at around 300 mb). An

upper-level disturbance would, therefore, seem relevant to this occurrence, since wind speeds were high, with fairly large fluctuations, at all levels throughout the day.

Final comments. The barograms for Liverpool Airport for the years 1960 to 1972 were studied for rapid pressure changes (3 mb or more in less than 30 minutes being considered) and also for signs of oscillation after such a change. The barogram for 5 December 1972 was then superimposed on any barogram with such a change in order to compare the rates of change. These comparisons are summarized as follows:

(a) There were seven occasions of frontal rates of change equal to or greater than that of the trough in question. All were rises of pressure.

(b) Several cases of changes of between 2 mb and 5 mb in 20 minutes or less occurred in association with thunderstorms observed at the station, some of which were very erratic, but no definite oscillation was noted.

(c) There were six cases which showed signs of an oscillation after a rapid change of pressure (considering either a rise or a fall) in association with either a front or a trough. The rate of change in all these cases was less than that of the trough in question, and none of the cases in (a) above was followed by an oscillation.

(d) The most noteworthy feature of the trough in question was that the pressure rise occurred suddenly after several hours of almost uniform pressure. It was the only such case at Liverpool in the 12 years considered.

Occurrences of this kind are not uncommon, but the magnitude of the rise following several hours of uniform pressure makes it noteworthy.

On the evidence available it would seem that this phenomenon was due to an upper-level disturbance.

Acknowledgement. The author would like to thank his colleagues for their help in preparing this article, especially Mr H. T. D. Holgate and Mr T. H. Kirk for their advice and suggestions as to its presentation.

REVIEW

Comparison between pan and lake evaporation, WMO *Technical Note* No. 126, by C. E. Hounam. 270 mm × 210 mm, pp. 52, *illus.*, Secretariat of the World Meteorological Organization, Geneva, Switzerland, 1973.

A reliable means of assessing water loss from reservoirs by evaporation has long been sought by water supply undertakings. Trustworthy evaporation data are also important for the planning, design and operation of irrigation and drainage facilities, navigation canals and other open water systems. The cheapest and simplest technique employs a pan (or tank), a water-level measure and a rain-gauge.

It is clear that the rate of evaporative water loss from a small, shallow tank will not be the same as from a large and relatively deep lake. The large water mass in the lake has a capacity to store heat which is not shared by the small sample of water in the tank, where changes of temperature will be, by comparison, both large and rapid. There are also other important differences involving friction, absorption and reflection of radiation, and lake-induced

microclimatic effects. Mr Hounam, an acknowledged authority on the subject, deals expertly and simply with present practices for using pans to monitor large-scale water loss by evaporation.

After a brief but comprehensive introduction to most of the types of pan or tank currently in use, the author deals with the important problem of siting the pan in relation to the lake (with an unfortunate printer's omission from para. 3.3.). He then discusses the effects of inflow, outflow, lake dimensions and surface wind waves. Attention is drawn to the importance of differences between the way in which radiation is absorbed and reflected by the lake and by the pan, and also to the differences between friction over the large water surface and the smaller, land-enclosed one.

The lake's own microclimatic effects are examined and also the difficulties experienced in obtaining true values of evaporation from pan and lake for the determination of 'lake-to-pan' coefficients. Coefficients for a selection of tanks and locations are listed and the well-known earlier *Technical Note* No. 83 is cited. Seasonal and spatial variations of coefficients are shown. The indirect Russian method employing both a small and a large tank is explained and also the use of floating tanks. Details are given of techniques involving the American Class A pan, an evaporimeter normally exposed on a stand, whereas most others are buried in the ground to within a few centimetres of their rims.

The collection and use of relevant meteorological data are summarized. The conclusions are realistic and are frankly presented; there is no attempt to avoid serious unsolved problems.

B. G. WALES-SMITH

Synoptic climatology: Methods and applications, by R. G. Barry and A. H. Perry. 240 mm × 160 mm, pp. xvi + 555, *illus.*, Methuen and Co. Ltd, 11 New Fetter Lane, London EC4P 4EE, 1973. Price: £6.50.

The authors of this book have, I think, had the praiseworthy aim of providing a basic course-book on the subject. They recognize it as not being a 'neat coherent field' and give one of its basic functions as the study of 'the nature of the relationships between atmospheric circulation systems and weather conditions, especially in particular geographical locations'. They have provided a very wide-ranging survey of the subject and offer much material for thought. Included along with well-established concepts are many of a highly speculative nature and it is not always made clear which is which. It is true the source of these latter ideas is always given in the very large bibliography, but many readers will not have access to the source papers. This procedure of including every opinion that has found its way into print may be acceptable in a review article but seems to me inappropriate in what is conceived as a textbook.

There are five sections, entitled: The basic data and their analysis; Synoptic climatological analysis; Statistical methods; Applications; Synoptic climatology; Status and prospects.

The first section contains matter which can mostly be found in standard texts on meteorology. The second contains a thorough description of methods of weather-type classification which, of course, is a vital element in the methodology of the subject. (It is a pity that the Baur–Hess–Brezowsky type HN was rendered into English, on page 123 and in Figure 3.13(c) as 'High over the North Sea' when the intention of the catalogue-makers was clearly 'High over

the Norwegian Sea'—a very different situation.) In a natural desire to give some order to the subject they say on page 88 that 'the Icelandic low at the surface is represented by the mean 500 mb trough over Eastern North America'. In the context of westward-sloping axes of synoptic systems with height, this view is so improbable an idea that it should not be slipped into a textbook without a great deal more discussion.

Not being an expert on statistics I cannot comment on the quality of the section on statistical methods, but I would prefer to see students referred to one or two suitable texts on statistics rather than being offered a compressed review which does not even include such fundamental items as significance levels for correlation coefficients or the other basic tests such as 'Student's' t, F-test, etc.

In the section 'Applications' the authors discuss the vexed matter of 'Singularities'. They start by noting the evidence against their reality but end up by describing other work with somewhat uncritical fervour.

Climatic change is also treated in this section; and despite the authors' attempt to create a sensible picture the scene remains very confused. The confusion will not be lightened by an unfortunate misprint on the third line of page 378, where ^{18}O has become 180 in a reference to the amount of oxygen isotope (^{18}O) in the ice core retrieved in north-west Greenland in 1966. There is also a reminder that it is not only changes of circulation type which lead to secular changes in temperature but that there are changes in temperature within a circulation type from one epoch to another.

The 'quasi-biennial oscillation' and solar–terrestrial relationships are helpfully discussed, and the small amplitude of both effects is stressed. The authors do not, surprisingly, do this in discussing lunar-weather relationships.

There is an enormous amount of interesting and thought-provoking material in these 450 pages but as said earlier its quality is mixed, and I feel that it is expecting too much of students to expect them to exercise so much discernment.

The book is very nicely printed and the diagrams are abundant and (with a very few exceptions) exceptionally clear and easy to read.

M. K. MILES

PUBLICATIONS RECEIVED

The following have been received from the Meteorological Institute of the University of Thessaloniki:

Meteorologika 23: *Weather-types and sunshine-duration in the west coast of the Aegean Sea.* By A. A. Flocas and P. J. Pennas. 1972.

Meteorologika 24: *Ground surface temperature.* Part II. Grass-covered ground. By G. C. Livadas and Y. A. Goutsidou. 1973.

Meteorologika 26: *Atmospheric-pressure in Thessaloniki—Greece.* By G. C. Livadas and T. J. Makroyannis. 1973.

Meteorologika 27: *Cloudiness in the major area of Thessaloniki.* By V. A. Angouridakis. 1973.

Université de Thessaloniki. *Annuaire de l'Institut Météorologique et Climatologique*, **39**. Observations Météorologiques de Thessaloniki 1970, publiées par le Prof. Dr. G. C. Livadas, Thessaloniki, 1973.

Université de Thessaloniki. *Annuaire de l'Institut Météorologique et Climatologique*, **40**. Observations Météorologiques de Thessaloniki, 1971, publiées par le Prof. Dr. G. C. Livadas, Thessaloniki, 1973.

Université de Thessaloniki. *Annuaire de l'Institut Météorologique et Climatologique*, **41**. Observations Météorologiques de Thessaloniki, 1972, publiées par le Prof. Dr. G. C. Livadas, Thessaloniki, 1973.

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LETTER TO THE EDITOR

The Thorpe Bay–Foulness tornado

Mr C. I. Griffiths, in his interesting account of the south-east Essex tornado,[1] suggests that the phenomenon may have been initiated by heated effluent from a power station situated some 15 miles upwind from the initial region of wind damage. From my study of funnel-cloud formation to the lee of factory chimneys (which the author refers to in his paper) it appears that these vortices are relatively weak and generally short-lived, and so would be unlikely to produce winds of tornado strength even if they were able to retain their identity whilst travelling for some 30 minutes from source. Maximum surface-wind velocities appear to be somewhat less than those reported by Heighes[2] near the cores of aircraft-wing vortices.

Conditions were favourable on 7 August 1973 for heavy shower activity with strong downdraughts, and the Shoeburyness anemogram suggests the passage of a gust front. This may well have been associated with an active part of a secondary cold front which was crossing the area at about the time of the tornado. Broadly similar conditions were discussed by Goldie and Heighes[3] after studying a North American tornado. Also, in an experiment described elsewhere,[4] an artificial 'micro' gust front was found to initiate weak vorticity, as cold air moved over a warmer water surface.

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2. HEIGHES, J. M.; Vortices. *New Scientist, London*, **55**, 1972, pp. 108–109.
3. GOLDIE, E. C. W. and HEIGHES, J. M.; Investigation of a United States Midwest tornado. *Met Mag, London*, **101**, 1972, pp. 270–278.
4. HEIGHES, J. M.; Comment on 'steam devils' over Lake Michigan during a January arctic outbreak. *Mon Weath Rev, Washington, D.C.*, **100**, 1972, p. 750.

CORRECTION

Meteorological Magazine, February 1974, p. 49. In the second line of the Summary 'downwind' should read 'upwind'.

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VOL. 103 NO. 1223 JUNE 1974

CONTENTS

	Page
Retirement of Mr E. Knighting	149
The Meteorological Offshore Buoy Observing Equipment Experiment, 1972. K. J. T. Sands	150
Noctilucent clouds over western Europe during 1973. D. H. McIntosh and Mary Hallissey	157
The tornadoes of 26 June 1973. K. W. Whyte	160
Rapid pressure rise followed by an oscillation of pressure during the passage of a trough at Liverpool Airport on 5 December 1972. J. A. Young	171
Review	
Comparison between pan and lake evaporation, WMO *Technical Note* No. 126. C. E. Hounam. *B. G. Wales-Smith*	177
Synoptic climatology: Methods and applications. R. G. Barry and A. H. Perry. *M. K. Miles*	178
Publications received	179
Letter to the Editor	180
Correction	180

NOTICES

It is requested that all books for review and communications for the Editor be addressed to the Director-General Meteorological Office, London Road, Bracknell, Berkshire, RG12 2SZ, and marked 'For Meteorological Magazine'.

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